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MODELING OF RADIATIVE HEAT TRANSFER IN CRYSTAL GROWTH

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Summary

This three month project was concerned with two major areas of research: (1) a numerical investigation of crystal growth from melt and (2) the development of a combined heat transfer model for a Saphikon fiber growth furnace. Because of the shortness of time (3 months), both investigations had barely begun when the overall project was funded via another NASA cooperative agreement. Thus, all that can be stated here are basic aims of the work. A more complete story can be found in the Technical Reports of NCC3-208.

Crystal Growth from Melt

Radiation heat transfer affects crystal growth in both space and ground-based processing. The role of radiation heat transfer is even more prominent in the low-gravity environment of space where convection heat transfer is minimized.

The technical objective of this research was to provide a quantitative understanding of the effects of radiation heat transfer on crystal growth. The effort was divided into two tasks. These tasks were directed towards addressing several critical aspects of costly space experiments.

The first task involved a rigorous formulation of the radiative link between the furnace and the crucible. This is essential for the development of more reliable models which can serve both the experimentalist and the furnace builder in the design of better experiments and more efficient furnaces. This is especially true in regards to crystal growth from vapor.

The second task addressed the effect of radiation on crystal growth from the melt with special attention given to the role radiation heat transfer plays in the energy balance at the interface and in the volumetric cooling of the solid. This task emphasized the space processing of those semiconductor and optical crystals which are of fundamental technological importance.

The overall aims of this research activity were:

- to elucidate the complex interaction among the different heat transfer modes during crystal growth and hence enhance our fundamental understanding of the physics associated with phase change phenomena;
- to facilitate the interpretation of experiments by directly incorporating radiation effects into crystal growth models, with the hope of resolving some of the previous space results for which no clear explanation exists;
- to identify the effect of thermal radiation on the solidification of important electronic, optical and oxide materials such as silicon, gallium arsenide, cadmium telluride, lead bromide, YAG and sapphire; and
- to demonstrate the impact of the crucible's radiative properties on furnace efficiency and on the thermal control of the experiments.

While specifically developed for crystal growth, the numerical models proposed in this research will directly apply to other branches of microgravity sciences such as combustion and glass processing in which radiation plays an equally important role. The model will be applied to designated space experiments such as the ones undertaken by GTE (gallium arsenide from melt), Boeing (cadmium telluride from vapor) and Westinghouse (lead bromide from melt). All of these experiments, which cover a broad range of materials processing in space, involve semi-transparent absorbing-emitting materials (in either the solid, the melt or the vapor phases).

In short, the results of this work show that application of pure conduction-convection models to these experiments is inadequate.

Combined Heat Transfer Model for the Saphikon Fiber Growth Furnace

In industrial applications sapphire fibers are grown in a furnace which allows an array of fibers to be pulled simultaneously from the melt. A 3-D combined conduction-radiation model is being prepared. The FIDAP computer code is used to describe the heat transfer process in the complex furnace designed by GE and Saphikon for growth of multiple sapphire fibers. Computation of the radiation view factors for the complicated 3-D furnace geometry, which involves numerous third surface shadowings, is very difficult. Effort is underway to formulate and analyze three sub-problems associated with this furnace:

1. A combined radiation-conduction-convection and electric potential model for the heaters.
2. A. combined radiation-conduction-convection model for the dye tip section.
3. A 3-D combined heat transfer model representing the general heat transfer in the furnace.